

A COMPREHENSIVE BIBLIOMETRIC ANALYSIS OF RENEWABLE ENERGY

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Abstract

The provision and use of energy at the national level have implications for national economic prosperity, energy security, and international relations. It is widely accepted that in a world with limited resources, there is an urgent need to reduce and even halt carbon emissions. In this context, the development and adaptation of the energy sector to new realities become relevant for the global economy. This paper aims to emphasize the importance and timeliness of the topic by conducting a literature review using a bibliometric approach. Utilizing such a method is vital for understanding the significance of the researched theme and for quantifying the level of existing research on renewable energy to date. By conducting this research, gaps and developments can be highlighted, and new approaches can be identified that have either not yet been addressed or can be further explored. Thus, through bibliometric analysis, the relevance of the topic is substantiated, and new research directions can be outlined. The practical implications of this paper are represented by highlighting the importance of the topic and identifying gaps in interstate academic cooperation, which, if addressed, could lead to improvements in the quality of research in the field.

Keywords

Bibliometric analysis, Renewable energy, Visualization, Energy security, Bibliometrics, Web of Science

JEL Classification

Q200, Q010, Q520, Q560, Q550

Introduction

In the current context, there is a need to find and implement solutions and strategies that lead to a reduction in dependence on energy resources, ultimately aimed at stimulating economic growth and development. The current economic model used at the national level is unsustainable and could lead to high long-term costs for humanity, resulting in an increased deficit of natural resources, exceeding limits imposed on air and water pollution, causing a series of major and irreversible climate changes, as well as significant losses in biodiversity. Therefore, it is necessary to carry out a series of

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sustainable investments in the energy sector, both at the European and national levels, which stimulate the production and use of renewable energy, protect natural resources—justified by their finite nature—and thus promote other branches of the economy. By implementing such economic models, states can gain competitive advantages in the energy sector, as well as in all other complementary areas where energy is predominantly used within the production cycle. It is essential to monitor and analyze long-term benefits, considering that the economy should not serve individual interests or be solely for private property, nor should it cater to those who aim to use the state to impose personal values or secure the hierarchy of their interests. In other words, the global economy must operate for the common good. Consequently, the well-being of the community encompasses both individual dimensions and perspectives as well as collective ones. Based on this idea, the task of the economy is to identify policies and practices that promote the common good (Tirole et., 2017).

The long-term strategy of states consists of promoting economic development, enhancing community well-being, and achieving socio-economic balance, while not neglecting the interaction between the environment and energy-producing activities. Efforts to limit environmental pressure have become an increasingly pressing concern, and Romania aims to alleviate this pressure to minimize the effects of a potential environmental crisis, which would undoubtedly lead to an economic crisis with a significant socio-economic impact.

All these challenges involve a series of essential changes regarding consumption perspectives at the societal level (Jackson, 2002). Although limited, progress has been made in terms of international agreements to combat and limit climate change, influencing the scientific community to study the public's perception of energy availability (Corner et al., 2011). There are studies investigating consumers' willingness to pay for energy from renewable sources (Longo, Markandya, and Petrucci, 2008).

Romania's energy landscape faces significant challenges and opportunities in an ever-changing global context. Electricity production, as a fundamental element of the energy infrastructure, plays a crucial role in shaping the country's economic development. In recent decades, Romania has undergone a series of transformations in the energy sector, influenced by both internal and external policies, as well as international commitments regarding sustainability and energy transition.

This study aims to answer questions such as what is the research trend in the field of renewable energy during the analyzed period, what are the domains in which this topic is studied, and which countries are the most interested in researching this subject to analyze the collaborations between them and what are the main keywords used in the research. The answers provided in the research justify the practical implications of the importance of the study through the arguments presented for each question that initiated the bibliometric analysis.

This article aims to analyze the status of research conducted in the field of renewable energy in recent years, as well as its evolution from 2001 to the present, given the importance and timeliness of this subject. Additionally, through the research, an evaluation of current data and trends will be carried out, with the present study aiming to provide a comprehensive overview of research in the field of renewable energy.

1. Review of the scientific literature

Renewable energy is considered "the key to a cleaner and more sustainable energy future" (A. Zahedi, 2011), and economic development at the state level is closely correlated with the development of this field. This approach is in full accordance with the objectives of sustainable development. On the other hand, financial stability, as well as the increase in innovation in renewable sectors, are genuine pathways to meet the conditions for achieving significant and sustainable economic growth (Guan et al., 2020). However, it has been observed that during this time, sustainable development has taken on an essential role and has emerged as a field for international organizations, governmental powers, and researchers as well.

Nonetheless, sustainable development gives meaning to the concept of green energy, which is considered the most relevant for improving the development level of the population and enhancing the quality of life (Administration, UNDF P and Management, D, 2008). Vakulchuk et al. (2020) argue that renewable energy can help reduce geopolitical tensions related to traditional energy resources. The hypothesis presented gains credibility in the current geopolitical context, marked by significant unpredictability. However, the contemporary national economic model, widely practised, has devastating effects on the environment due to the negative externalities generated, including high CO₂ emissions (Zafar et al., 2021), and globalization and economic growth are associated with an increase in CO₂ emissions (Xia et al., 2022).

This improvement in economic performance in the energy sector is influenced by a series of factors and measures taken at the national level, such as ensuring a stable regulatory framework. Although the transition initially involves significant costs, the long-term benefits are considerable, and at the national level, legislation plays an essential role in ensuring a sustainable, safe, and efficient sector (Petcu et al., 2023).

The shift to renewable energy sources can stimulate economic growth, reduce dependence on fossil fuels, and enhance energy security through investments made by companies in the development of solar, wind, and hydroelectric energy (Nishitani et al., 2011). However, in a perpetual race, companies are the most relevant parties, with their behaviour undergoing a metamorphosis, considering the actions of other stakeholders that sanction less responsible ecological and social behaviour of these entities, as well as the pressure from shareholders to maximize profit (Drăcea et al., 2020). Companies' business strategies have adapted in recent decades by incorporating ESG aspects (Noja, G. et al., 2023).

Starting from the potential to save time, resources, and imports, energy efficiency has become a strategic objective (Hirst and Brown, 1990). When analyzing the potential of renewable energy for firms, it is important to note that this type of investment aims to enhance competitiveness (Moreno et al., 2014; Drake and Spinler, 2013), as this will also improve labour productivity and the efficiency of the resources attracted and utilized (Gopalakrishnan et al., 2001). Thus, promoting energy efficiency, combined with reduced consumption, contributes to increased economic efficiency (Fan et al., 2017).

Furthermore, research in recent years on integrating green energy within firms has addressed this issue from an environmental perspective when demonstrating the influence of economic growth and energy consumption (Lee and Olasehinde-Williams,

2021; Wang and Lee, 2022), financing renewable energy, implementing innovation in the field, and analyzing and improving production (Wen et al., 2022; Lv et al., 2024; Lee and Lee, 2022; Zhang, 2022).

Therefore, it can be observed that to develop renewable energy and benefit from all the premises and advantages of sustainable development, it is necessary for economic and social progress to coexist without harming the environment. On the other hand, looking beyond economic growth, modernization, and emission reduction through the use of renewable energy, it is important to recognize that additional pressure is generated at the microeconomic level regarding the adoption of ecological practices (Zhang, 2022).

Given the importance of the subject and the need for development in the field, the research will conduct a bibliometric analysis. This method represents a relevant indicator that highlights quantitative indicators of scientific works. On the other hand, the general purpose of bibliometrics is to measure scientific works using mathematical calculation methods and by generating statistical data, which is subsequently subjected to analysis (Valentina Donici, 2023).

2. Research methodology

To conduct this research, a review of the specialized literature was carried out using a quantitative research method, namely bibliometric analysis. For the study, the Web of Science database was queried using the keywords "renewable energy" from October 21, 2024 to October 28, 2024. Following this query, a total of 295,392 results were obtained. Given the large number of identified articles, it was noted that they came from various fields, and to narrow down the searches, the "economics" filter was added to the Web of Science categories, thus reducing the results to 7,607 publications. The results obtained and filtered were then sorted according to the highest number of citations. The period subject to analysis is extensive, covering the years 2001-2024, and the sample created based on the analyzed data includes the top 1,000 most cited publications. The period of analysis between 2001 and 2024 was selected for the bibliometric analysis of sustainability because it reflects the substantial development of research in this area, including phases of heightened global interest in environmental issues, climate change and sustainable development, as well as the implementation of major international policies and initiatives in this regard. After collecting and filtering the data, it was processed using the VOSviewer program.

The analysis focused on several aspects; in the research, it can be observed that various criteria were used, such as years, keywords, countries, authors, number of citations, the countries most interested in renewable energy research, affiliations, as well as the fields that investigate this issue. The analysis was conducted for each cluster obtained with the help of the VOSviewer application, as well as for the other graphical representations created within the research.

The Web of Science (WoS) is considered worldwide to be the largest information database, managing to cover a multitude of disciplines (Falagas et al., 2008). It represents a reliable source, with high-quality content, which serves to provide researchers with varied, accurate, and trustworthy academic information, thus becoming over time the main source of data provided and used in bibliometric analysis research (J. Guan et al., 2020).

3. Results and discussions

Based on the data obtained using VOSViewer software, results regarding the bibliometric analysis have been generated, and these are discussed in the following subsections. The results obtained from querying the Web of Science database, processed using VOSViewer software, provide a detailed picture of research trends in the field of renewable energy. The software allows for the visualization of citation networks and collaborations between authors, facilitating the identification of significant structures and relationships within the specialized literature.

Through data analysis, we observed a consistent increase in the number of publications in the field of renewable energy, reflecting a growing interest and increased concentration of resources in this sector. The maps generated by VOSViewer clearly illustrate the clustering of research themes, highlighting popular and emerging topics.

Additionally, the analysis of international collaborations revealed an extensive network of partnerships among institutions from various countries, underscoring the importance of interdisciplinary and intergovernmental collaboration in advancing knowledge in the field. The collaboration maps between authors and institutions suggest not only the most active countries in research but also the institutions where the research is conducted.

These results not only demonstrate the dynamics of research in renewable energy but also provide insights into future directions for study, contributing to the understanding of complexity and interdependence in this essential sector for sustainability. Regarding the practical implications of the results obtained, they should have a significant impact on decision-makers, particularly in the development of public policies and investment strategy planning. The increase in publications in the renewable energy sector highlights its growing importance for economic development and sustainability. Therefore, decision-makers should prioritize this field by supporting both research and the implementation of policies that encourage the transition to renewable energy sources.

The international collaborations identified in the analysis emphasize the need for closer cooperation between countries and institutions, which could lead to more efficient solutions for common issues, and the harmonization of processes, procedures and legislation. In this regard, states should invest in strengthening these partnerships and decision-makers should create frameworks that stimulate collaboration between the public and private sectors, institutions, countries and different fields of activity. Identifying the most popular research topics and emerging trends in the renewable energy field can guide the efficient allocation of research and development funds, contributing to the development of innovative and sustainable solutions, so decision-makers must integrate these findings into policies that support progress and ensure a greener and more energy efficient future.

3.1 Keyword Analysis

Figure 1 represents a network of keywords grouped into clusters, with the central concept represented by "renewable energy." Based on the identified colours and connections, it can be observed that the map reveals three main clusters.

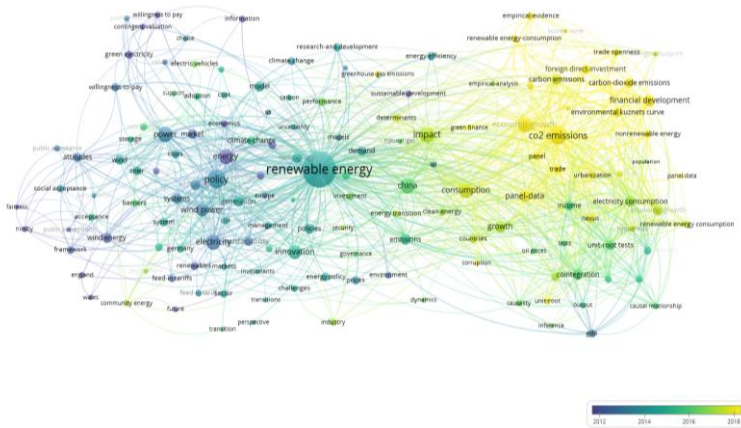


Figure 1. Keywords

Source: Authors' own conceptualization using VOSViewer software

The central cluster, in which the phrase "renewable energy" is identified, is associated with terms such as demand, models, innovation, energy policy, and perspective. The yellow cluster includes terms related to CO2 emissions, trade, consumption, carbon emissions, and urbanization—words that describe environmental issues. The purple cluster includes terms such as green electricity, energy, wind energy, and economics, which are keywords that offer solutions to the identified and discussed problems.

3.2. Countries and Connections

The table below indicates the number of publications on the topic of renewable energy, categorized by country, creating a hierarchy among them.

Field: Countries/Regions	Record Count	% of 7,512
AUSTRALIA	472	6.283%
CANADA	237	3.155%
ENGLAND	706	9.398%
FRANCE	310	4.127%
GERMANY	810	10.783%
ITALY	306	4.073%
NETHERLANDS	305	4.060%
PEOPLES R CHINA	1,109	14.763%
SPAIN	287	3.821%
USA	1,323	17.612%

Figure 2. Keywords

Source: Web of Science

Analyzing the figure above, it can be observed that the largest contributions to research in the field come from the following countries: the USA with 17.6% of the total publications in the economic domain regarding the phenomenon, followed by Spain,

China, the Netherlands, Italy, Germany, France, England, Canada, and Australia. It can be noted that the USA has the highest number of publications; this presence is justified by its long-standing tradition in scientific research and the presence of top institutions that support innovation. Furthermore, American universities, federal agencies (such as the Department of Energy), and the private sector have actively contributed to renewable energy research, motivated by the increasing demand for sustainable solutions and regulatory pressures.

China's representative presence can be explained by the country's strong commitment to energy transition and reducing carbon emissions. With a total of 810 publications (10.783%), Germany ranks third, being one of the first countries in Europe to invest heavily in the energy transition (Energiewende). This aspect is a natural consequence of the German state's desire to increase energy independence. Additionally, this growing trend at the European level regarding the studied phenomenon is also observed in the other analyzed states. Italy and France represent countries that reflect the European commitment to sustainability and the green transition, being required to comply with European policies such as the European Green Deal and decarbonization targets.

The figure below, namely Fig. 2, presents a network of international collaboration between different states in renewable energy research. In this network, each node represents a country, while the lines indicate partnerships and the intensity of cooperative relationships between them. The colour and positioning of the nodes indicate collaboration groups and levels of interaction intensity.

European countries are represented by the red colour of the cluster, while France, Italy, and the Netherlands form another important group, reflecting the high level of cooperation within the European Union. Common policies implemented at the European level stimulate collaboration between member states, facilitating joint projects and the dissemination of research. This collaboration aims to accelerate the development of renewable energy in Europe and adapt energy markets to new energy sources.

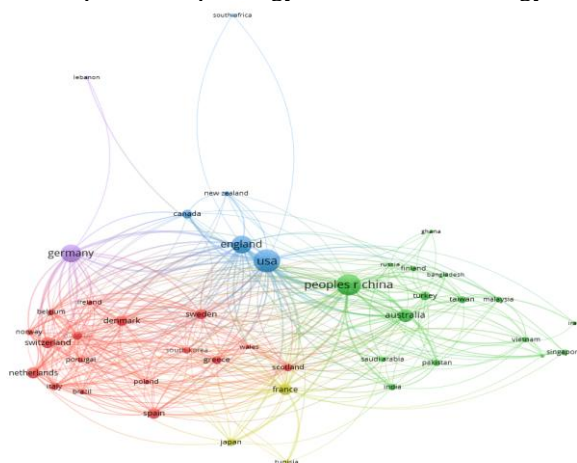


Figure 3. Collaboration Between Countries

Source: Authors' own conceptualization using VOSViewer software

The network reveals the division of international cooperation into three major regions: China as the Asian pole, the USA and Germany as transatlantic poles, and the European Union as a compact and well-connected bloc. These centres of collaboration indicate distinct strategic orientations: China is expanding its global influence, the United States and Germany dominate through technological innovation, and the EU operates through intensified regional cooperation.

The interdependence between these clusters shows that the issue of renewable energy is a global challenge, and research in this field requires a constant exchange of knowledge and resources. The existing collaboration blocks provide a solid framework for advancing energy technologies and can significantly contribute to achieving global emission reduction goals and adapting to climate change.

3.3. Trend in the Number of Citations and Publications

The trend in the number of publications in the field of renewable energy is a natural consequence of global pressures to accelerate the process of achieving an efficient energy transition. The current context, dominated by climate concerns, instability in energy markets, and national and international commitments, supports the amplified development of academic research in this area.

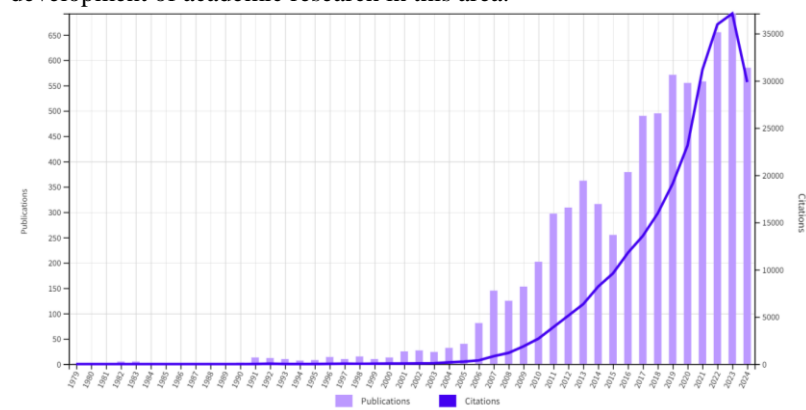


Figure 4. Trend in the Number of Citations and Publications
Source: Authors' own conceptualization using VOSViewer software

However, reaching a saturation point or stabilization of the growth rate is possible as solutions become increasingly viable and widely implemented. The graph shows a consistent increase in the number of publications and citations in the field of renewable energy, especially starting from the 2000s, with a rapid and nearly exponential rise in recent years. This trend can be attributed to several geopolitical, economic, and social factors that have heightened global interest in renewable energies and stimulated research activity.

3.4. Research Areas

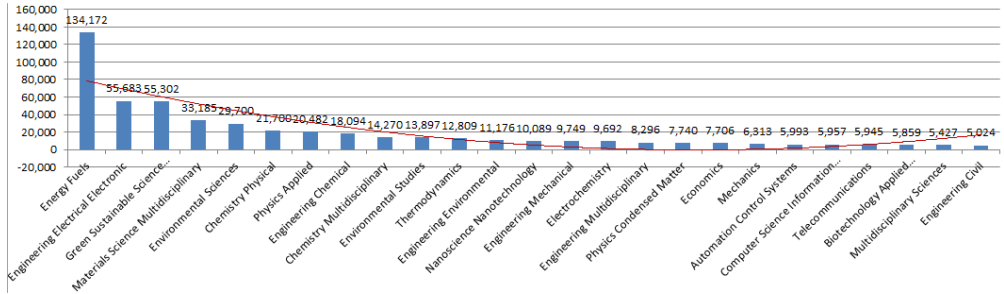


Figure 5. Research Areas
Source: Authors' conceptualization

The graph in Figure 5 illustrates the interest in renewable energy research across various fields of activity. We can see that, although the greatest interest in researching this topic comes from fields such as economics, environmental studies, energy fuels, environmental sciences, and business and management, there is also interest in this topic from other fields such as law, geography, transportation, political science, and international relations. This high number of fields studying this issue demonstrates its interdisciplinary nature, as well as the complex implications this sector has on the economy and social, governmental, and even interstate relations.

3.5. Authors and Affiliations

The figure below presents a diagram of the most active authors in renewable energy research, representing the number of publications for each author through the size of the rectangles and numerical values. This representation highlights individual contributions and provides insight into the authors who have dedicated a significant portion of their work to researching this field.

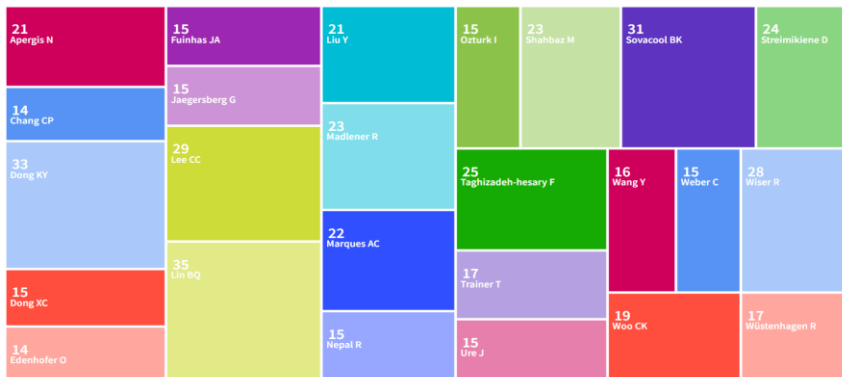


Figure 6. Authors and Affiliations
Source: Web of Science

It is remarkable that a significant number of authors have between 15 and 17 publications, this distribution suggesting an extensive and diverse research community.

With their expertise, they play a role in impacting how renewable energies are understood and applied in the current context.

Field: Affiliations	Record Count	% of 7,607
UNITED STATES DEPARTMENT OF ENERGY DOE	258	3.392%
UNIVERSITY OF CALIFORNIA SYSTEM	132	1.735%
NATIONAL RENEWABLE ENERGY LABORATORY USA	126	1.656%
UNIVERSITY OF LONDON	108	1.420%
HELMHOLTZ ASSOCIATION	94	1.236%
SWISS FEDERAL INSTITUTES OF TECHNOLOGY DOMAIN	90	1.183%
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	88	1.157%
UNIVERSITY OF CALIFORNIA BERKELEY	88	1.157%
LAWRENCE BERKELEY NATIONAL LABORATORY	85	1.117%
BUCHAREST UNIVERSITY OF ECONOMIC STUDIES	74	0.973%

Figure 7. Hierarchy by Affiliation

Source: Web of Science

The figure 7 provides an overview of the institutions that have contributed the most to research in the field of renewable energy. These institutions are predominantly from countries with advanced research infrastructure and strategic interests in the energy transition. Leading institutions, mainly from the United States and Europe, demonstrate the important role that major economic and scientific powers play in promoting green energy technologies. The United States Department of Energy (DOE) is the global leader in renewable energy research, followed by the University of California System, National Renewable Energy Laboratory USA, University of London, Helmholtz Association, Swiss Federal Institutes of Technology Domain, Centre National de la Recherche Scientifique (CNRS), University of California, Berkeley, Lawrence Berkeley National Laboratory, and the Bucharest University of Economic Studies (ASE).

Regarding the Bucharest University of Economic Studies, a total of 74 articles on this topic can be observed, and the faculty represents an important actor for Romania in the context of renewable energy research. Given Romania's proximity to the Russo-Ukrainian conflict and the deterioration of relations with Russia caused by it, Romania faces challenges regarding energy security. Therefore, the research conducted at the Bucharest University of Economic Studies plays a particularly important role in studying the impact of investments in renewable energy sources and economic and energy policies. Additionally, these research efforts aim to explore opportunities for reducing dependence on energy resources from external sources. In the current context, the research undertaken by ASE is relevant for identifying the best solutions in the sustainability sphere, allowing Romania, on the one hand, to enhance its energy independence by ensuring national energy needs, and on the other hand, to diversify its energy sources.

Limitations

Although a bibliometric analysis was conducted over a considerable period from 2011 to 2024, examining various aspects such as the number of publications and citations by year, authors, countries, and relationships between countries and affiliations, there are still some limitations. This article relied on a single database source, namely Web of Science, and the specific settings applied may lead to the omission of publications from fields other than economics that could be relevant to the topic under analysis. Future research will consider diversifying the databases, and terms, and processing a larger number of results. This research focuses on providing an overview of the field, but further studies are planned to enable a more in-depth and detailed analysis. Despite these limitations, the research reflects the current state of research in renewable energy within the economic field and contributes to understanding research trends in this area, as well as outlining new objectives and areas of interest for future studies. Other potential errors may include data updates, as the analysis was conducted in 2024, and some recent publications may not have been included, which could affect the final results. Additionally, the use of automated data processing tools could lead to various material errors during the processing stage.

Conclusions

This paper presents a bibliometric analysis of relevant publications from an economic perspective on a topic of interest studied across various fields, highlighting study trends, the most interested countries, and the academic collaboration relationships that develop between researchers and at the interstate level. By analyzing keywords, assessing the current level of interest in renewable energy research, and tracking the evolution of publications and citations over the years, the study reveals the relationships established between authors and countries.

The bibliometric analysis focuses on the 1,000 most cited publications in the economic domain regarding renewable energy. However, as shown in Fig. 5, the number of fields in which such studies are conducted is diverse, ranging from economics, business, management, environment, ecology, law, transportation, and geography to international relations. The results obtained underline a growing interest in the subject under analysis over the past ten years, although interest in the topic began as early as 1991, with fluctuating study trends over the years. The topic of renewable energy was most intensively addressed in 2023; however, for 2024, this situation is not finalized, as it pertains to the current year.

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